CCAMLR Science, Vol. 8 (2001): 155–163

SHORT NOTE

THE USE OF PREDATOR-DERIVED KRILL LENGTH-FREQUENCY DISTRIBUTIONS TO CALCULATE KRILL TARGET STRENGTH

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Abstract

The relationship between krill abundance and predator performance is fundamental to an ecosystem-based approach to resource management. We propose a method using krill sampled from the diet of predators to provide a length-frequency distribution of krill at times when it is possible to run automated shipboard acoustic systems but not to conduct scientific netting, i.e during logistic/resupply operations. This will allow a robust estimate of krill abundance to be calculated from acoustic data. Changes in the length-frequency distribution of krill over a period of a few weeks produced a 10% difference in TS, whereas simultaneous samples from predators and nets produced only a 1% difference, illustrating the need for simultaneous length-frequency data. By integrating data from land-based predators directly with automated on-board data collection systems it will be possible to gain important estimates of krill biomass at times of the season hitherto unavailable from shipboard scientific surveys.

Résumé

La relation entre l'abondance du krill et la performance des prédateurs est fondamentale à l'approche de gestion des ressources fondée sur l'écosystème. Nous proposons une méthode qui, au moyen des échantillons du régime alimentaire des prédateurs, fournit une distribution de fréquence des longueurs du krill. Cette méthode s'avère utile lorsqu'il est possible d'utiliser des systèmes acoustiques automatiques du navire mais pas de prélever des échantillons scientifiques au filet, à savoir, lors des opérations logistiques/de ravitaillement. Il sera ainsi possible de calculer une estimation robuste de l'abondance du krill à partir des données acoustiques. Les changements de distribution de fréquence des longueurs de krill sur une période de quelques semaines provoquent une différence de 10% de réponse acoustique, alors que les échantillons simultanés des prédateurs et des filets n'affichent qu'une différence de 1%, ce qui met en évidence la nécessité d'obtenir des données simultanées de fréquence des longueurs. En regroupant les données des prédateurs terrestres avec celles fournies directement par les systèmes automatiques de collecte des données du navire, il deviendra possible d'obtenir, pour certaines périodes de la saison, des estimations importantes de la biomasse de krill que n'avaient jamais pu produire les campagnes d'évaluation scientifiques menées à partir de navires.

Resumen

La relación entre la abundancia de kril y el comportamiento de los depredadores es fundamental para el enfoque de ordenación de los recursos basado en el ecosistema. Se propone un método para estimar la distribución de la frecuencia de tallas utilizando el kril muestreado de la dieta de los depredadores cuando el uso de sistemas acústicos automáticos a bordo es posible pero no es factible realizar una prospección científica de muestreo con redes, por ejemplo durante las operaciones logísticas y de reabastecimiento. Este método permitirá calcular una estimación fidedigna de la abundancia de kril a partir de los datos acústicos. La variación de la distribución de la frecuencia de tallas de kril observada en un período de varias semanas produjo una diferencia de 10% en la potencia del blanco (TS), mientras que la diferencia en TS observada de las muestras tomadas simultáneamente de los depredadores y de las redes fue solamente de 1%, indicando que es necesario obtener datos simultáneos de la frecuencia de tallas. La integración directa de los datos obtenidos de los depredadores terrestres con los datos obtenidos a bordo mediante sistemas automáticos permitirá realizar estimaciones válidas de la biomasa de kril en las temporadas cuando es imposible realizar prospecciones científicas a bordo de barcos.

Резюме

Взаимосвязь между численностью криля и продуктивностью хищников является ключевой частью экосистемного подхода к управлению ресурсами. В статье предлагается метод, позволяющий использовать данные о криле в рационе хищников для оценки частотного распределения длин тогда, когда на судне могут использоваться автоматические акустические системы, но не могут проводиться научные траления, например во время проведения материально-технических/снабженческих операций. Это позволит получить робастную оценку численности криля по акустическим данным. Изменение частотного распределения длин криля на протяжении нескольких недель привело к 10%-ной разнице в TS, в то время как для одновременно полученных данных по хищникам и тралениям разница составила только 1%, что показывает необходимость таких данных. Использование данных по рациону наземных хищников непосредственно в автоматических бортовых системах сбора данных позволит получать важные оценки биомассы криля по периодам сезона, до этого не охваченных бортовыми научными съемками.

Keywords: krill, target strength, length frequency, predators, diet, resource management, ecosystem, CCAMLR

INTRODUCTION

The relationship between prey availability and the reproductive performance of dependent species is fundamental to the operation of an ecosystem approach to resource management and to understanding the response of predators to environmental changes. In many cases variability in prey availability has been inferred from changes in predator performance. Clearly, in order to consider the interaction between these two factors, measures of prey availability need to be independent to avoid interrelated estimates. For South Georgia, there is a 20-year time series of data on the reproductive performance of krill-dependent predators such as Antarctic fur seal (*Arctocephalus gazella*). Surveys of krill abundance around South Georgia have been conducted annually since 1996 (Brierley et al., 1997), and more infrequently since 1981 (Brierley et al., 1999), as a component of multidisciplinary oceanographic research cruises.

The reproductive performance of penguins and seals reflects prey availability over the entire breeding period, from October to March, however estimates of prey abundance are usually available only for short periods, coincident with research cruises. There is increasing evidence that both the population structure and availability of krill to predators can change markedly over the course of the breeding season (Reid at al., 1999a; Reid, 2000). For example, krill availability may be low in October–November but may have increased considerably by January, when the acoustic estimate is typically conducted. Thus, at the onset of breeding there may be a high initial offspring mortality, producing low overall breeding success, yet krill availability measured later in the breeding season may not appear anomalously low.

Given that most indices of predator performance usually reflect conditions over periods of at least a month, and generally longer, while acoustic estimates are conducted over periods of a few days, it is not practicable to limit the comparison of prey availability and predator performance over equivalent temporal scales. However, conducting research cruises to obtain acoustic estimates of krill availability throughout the foraging range over the entire predator breeding season would not be feasible given the financial and logistic demands of such an operation.

Integrated along-transect echo-intensity data collected during acoustic surveys are scaled to krill abundance using target strength (TS). TS is the ratio (in decibels, dB) that quantifies the intensity of sound, at a given frequency, backscattered (reflected) by krill compared to the intensity of the transmitted (incident) acoustic pulse, and is dependant on, *inter alia*, krill length (Foote et al., 1990). CCAMLR has adopted the TS-to-length relationship for krill proposed by Greene et al. (1991). An important component of an acoustic survey of krill, therefore, is an independent assessment of the length-frequency distribution of krill in the survey area. This length-frequency distribution has traditionally been obtained by net sampling. However, net sampling is time consuming and on a typical cruise may account for over 25% of time spent in the survey area. In addition, netting also has an associated personnel cost in terms of net rigging, fishing and maintenance, therefore netting operations typically require more manpower than do the purely acoustic components of the survey.

There exists the possibility to conduct acoustic surveys at South Georgia in association with voyages to the island that are primarily for field station resupply and other logistic purposes by allocating short periods of dedicated ship time to acoustic surveys. Although we can operate the echosounder on these voyages, we have neither the time nor the required personnel aboard ship for net deployment. In order to be able to scale acoustic data from these voyages to krill abundance, we need an alternate mechanism for estimating krill length frequency in our survey area. Since the population structure of krill at South Georgia is known to change markedly over short periods of time (Reid et al., 1999a), it would be insufficient to use, for example, an annual mean krill length frequency because this might introduce additional errors into the estimate of krill abundance. An estimate of the length-frequency distribution of krill concomitant with the survey period is required.

Recent work using krill in the diet of predators, in particular Antarctic fur seals at South Georgia, has revealed that, when considered at the appropriate spatio–temporal scale, the population structure of krill in the diet of predators is consistent with the population structure as sampled by shipboard scientific nets (Reid et al., 1996 and 1999b). Recent satellite-tracking studies of female Antarctic fur seals have shown a high degree of spatial overlap in foraging with the location of shipboard net sampling to the north-west of South Georgia (Boyd et al., 1998 and in press). Antarctic fur seals are present at South Georgia throughout the year, and samples of krill collected from their faeces can provide detailed information on changes in the population structure of krill at a temporal scale hitherto unavailable using conventional shipboard sampling methods (Murphy and Reid, in press).

The aim of this paper is to assess the potential for using predator-derived length-frequency distributions of krill to produce a TS estimate that can be used to facilitate additional krill biomass estimates from under-way acoustic data with minimum impact to shipboard operations.

MATERIALS AND METHODS

Sample Collection

Krill were collected from Antarctic fur seals at Bird Island, South Georgia, during the austral summers of 1994 and 1996–1999 (the austral summer is given as the second part of the split year, i.e. 1993/94 = 1994) from carapaces in scat samples collected during the lactation period (December–March) following the method of Reid and Arnould (1996). All krill used in comparisons with net samples were collected during the same 5–10 day period as net samples in each year.

Net samples of krill were obtained primarily using an RMT8. Samples were taken within the BAS Core Programme northwestern survey box (see Brierley et al., 1997) between December and February. In 1994, when numbers of krill caught were very low, the sample described here includes krill from both an RMT25 and a multinet (Brierley and Watkins, 1996).

Krill Measurement

All krill length measurements are given as the total length (AT): for net-caught krill, lengths were measured directly from the front of the eye to the tip of the telson (Lockyer, 1973); lengths from predators were estimated from the removed carapace length (RCL), using the appropriate regression models in Reid and Measures (1998) and Hill (1990).

Calculation of Target Strength from Krill Length

CCAMLR has adopted the individual krill length-to-target strength relationship proposed by Greene et al. (1991). We have used a derivation of

Table 1: The percentage difference in target strength (TS (dB kg^{-1})) calculated using the length-frequency distribution from net-caught samples (TS_{net}) and in the diet of Antarctic fur seals (TS_{pred}).

Year	TS_{net} (dB kg^{-1})	TS_{pred} (dB kg^{-1})	Difference (%)
1994	-38.64	-38.60	0.925
1996	-39.03	-38.76	6.414
1997	-38.60	-38.55	1.158
1998	-38.79	-38.64	3.514
1999	-38.40	-38.35	1.158

Table 2: The percentage difference in target strength (TS (dB kg^{-1})) calculated using the length-frequency distribution from net-caught samples (TS_{net}) and in the diet of Antarctic fur seals (TS_{pred}) after the application of a correction factor based on the proportion of krill of less than 40 mm (P_{40}) (TS_{cor} (db kg^{-1})).

Year	TS_{net} (db kg^{-1})	TS_{pred} (db kg^{-1})	P_{40}	TS_{cor} (db kg^{-1})	Difference (%)
1994	-38.64	-38.60	0.160	-38.71	-1.572
1996	-39.03	-38.76	0.514	-39.01	0.448
1997	-38.60	-38.55	0.016	-38.60	0.004
1998	-38.79	-38.64	0.392	-38.84	-1.196
1999	-38.40	-38.35	0.000	-38.39	0.156

this relationship that provides TS per kg of krill, rather than per individual (Brierley and Watkins, 1996), and which employs the krill wet mass-to-length relationship given by Morris et al. (1988). After measuring krill in a sample to the nearest millimetre, the mean TS of the distribution is calculated as the sum of all products of TS (dB kg^{-1}) per size class and the proportion that the size class contributes to the distribution as a whole.

RESULTS

The length-frequency distribution of krill in the vicinity of Bird Island can change markedly throughout the course of the predator breeding period between December and February (e.g. in 1994, see Figure 1). In 1994 this change in length-frequency distribution would have resulted in a 9.8% change in TS (dB kg^{-1}), and consequently in our estimate of krill abundance. This change illustrates the importance of obtaining an estimate of krill length frequency concomitant with the acoustic survey. In contrast, however, krill length-frequency distributions obtained simultaneously by nets and predators in 1994 would have resulted in only a 0.9% difference in TS (Table 1). The percentage difference between TS calculated using length-frequency distributions from nets and predators (Figure 2) ranged from 0.9% (1994) to 6.4% (1996) and is shown for all years in Table 1.

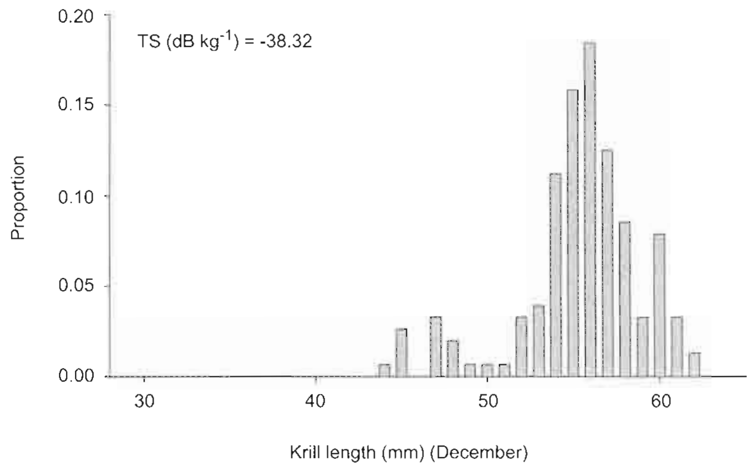
There was a significant correlation between the proportion of krill in the diet of predators of less than 40 mm AT and the percentage difference in the TS (dB kg^{-1}) values when compared to net samples (r = 0.93). A correction factor was developed based on this relationship:

$$TS_c = TS_p - 10\left(\log\left(1.01 + 0.0961 P_{40}\right)\right)$$

where TS_c is the corrected target strength (dB kg^{-1}), TS_p is the target strength (dB kg^{-1}) calculated from the predator length-frequency distribution and P_{40} is the proportion of krill smaller than 40 mm AT. When this correction factor was applied, the difference in TS calculated using nets and predators was reduced even further such that it ranged from only 0.004% to 1.5% (Table 2).

DISCUSSION

In any kind of survey there is a requirement to minimise as far as possible errors and biases that may reduce the accuracy of the final answer (see Demer, 1994 for a discussion of errors associated with acoustic surveys of krill). In a year such as 1994, when krill length at South Georgia changed markedly, the resultant 10% change in TS illustrates well the need for concurrent estimates of krill length and for accurate acoustic estimates of



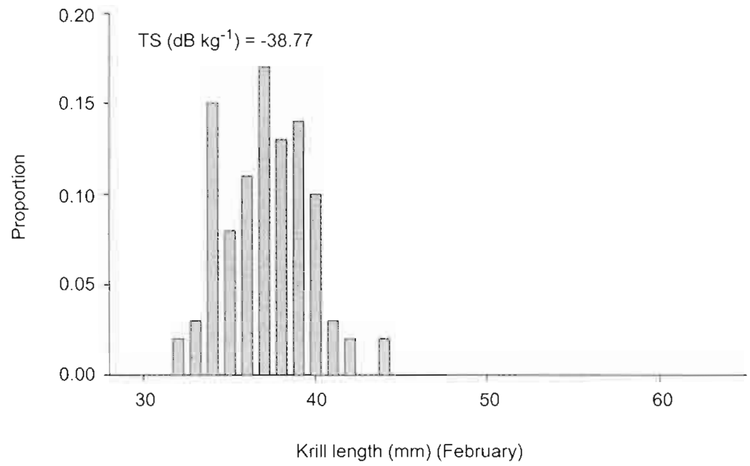


Figure 1: The change in length-frequency distribution and associated target strength (TS dB kg^{-1}) of Antarctic krill in the diet of Antarctic fur seals at Bird Island, South Georgia, between December 1993 and February 1994.

krill abundance to reduce error. When measured simultaneously, the TS (dB kg^{-1}) derived from predators and nets varied by less than 1%, and the use of predator data, therefore, does not introduce substantial errors into the estimate of krill biomass. The magnitude of the errors is low compared to the sampling errors due to between-transect variation in krill abundance, which commonly results in a survey variance of 20% (Brierley et al., 1999). By integrating data from land-based predators directly with automated on-board data collection systems it is possible to gain important estimates of krill biomass at times of the season hitherto unavailable.

The application of a correction factor to the data is required because Antarctic fur seals consume relatively few krill of less than 38 mm AT (Murphy and Reid, in press). In a multispecies comparison of krill from predators and nets Reid et al. (1999b) suggested using krill length-frequency distribution from Antarctic fur seals and macaroni penguins to cover the entire size range of krill available, since the latter took smaller-sized krill when available. Unlike Antarctic fur seals, macaroni penguins are present only from late October to March, and therefore simultaneous sampling of krill in their diet may only be possible depending on the timing of the early and late-season logistic calls to the island.

Linked changes in krill population structure and availability to predators over a scale of several weeks suggest that temporal extrapolation of point estimates of krill biomass must be approached with caution. By assessing the krill biomass at either end of the austral summer, in addition to the normal annual assessment in January, it may be possible to establish whether the variation in krill abundance is subject to systematic changes during the course of the predator breeding season. In particular, if

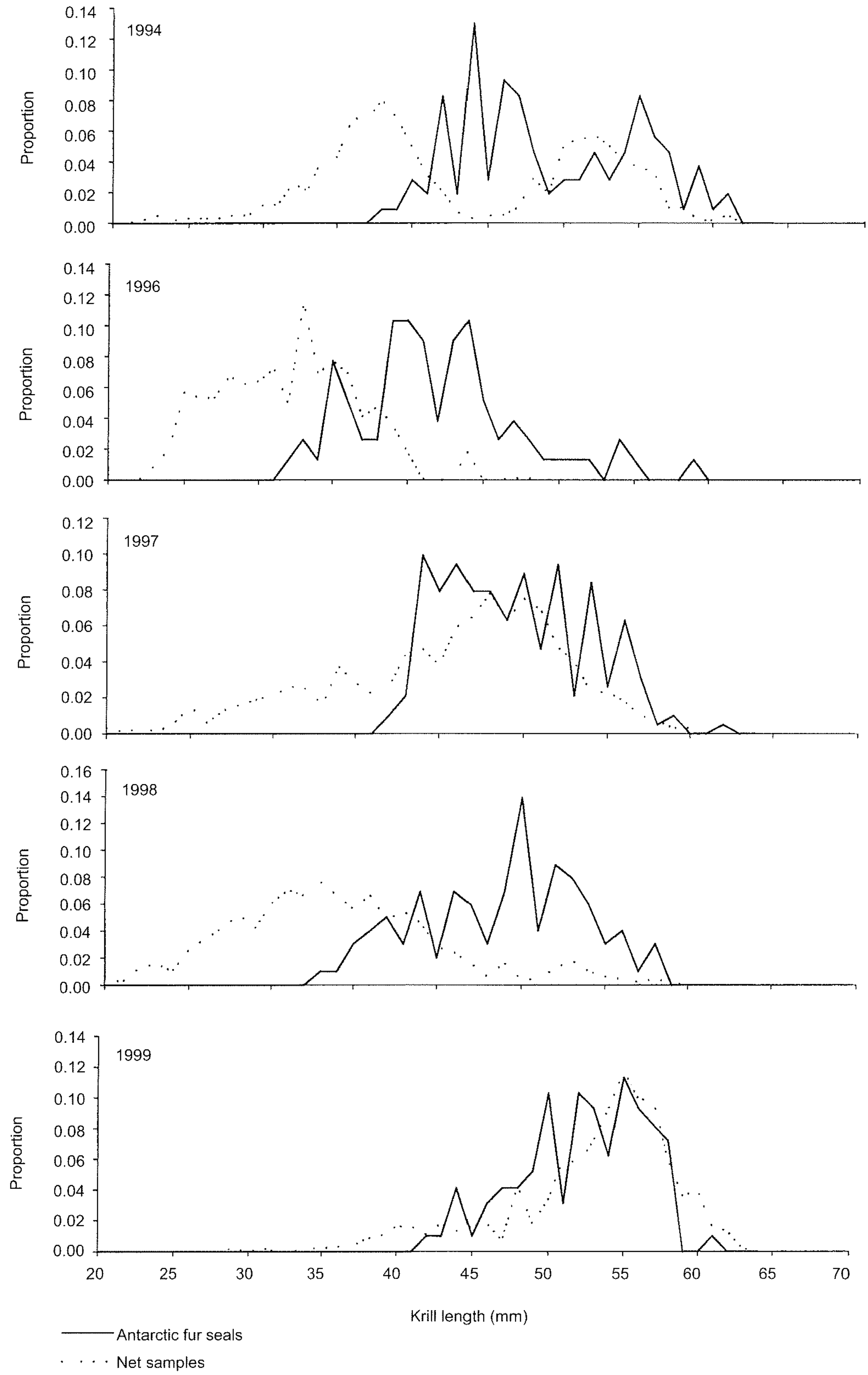


Figure 2: Length-frequency distribution of krill using simultaneously collected samples from Antarctic fur seals and shipboard net samples at South Georgia.

any such changes are associated with changes in krill population structure it may be possible to scale abundance and population structure to produce a more accurate description of intra-annual variability in krill and the response of dependent species over temporal scales not previously available.

CONCLUSION

Comparison of data on the performance of upper-trophic level predators and krill availability at congruent temporal scales, particularly at the onset of the breeding season and at the time when offspring first become nutritionally independent, is often limited by logistic constraints on ship-board operations. By using the length-frequency distribution of krill in the diet of predators to derive the TS of krill, the requirement to conduct scientific netting in conjunction with under-way acoustic measurements can be avoided without compromising the estimate of krill abundance. Application of this technique will enable us to collect additional estimates of krill abundance at the beginning and end of the Antarctic summer in conjunction with logistic/base resupply operations, in addition to the single estimate from a dedicated cruise.

ACKNOWLEDGEMENTS

We thank all our colleagues at the British Antarctic Survey who have measured krill, either acoustically, by hand on ship or from the diet of predators at South Georgia and Drs S. Kawaguchi and S. Kasatkina for helpful comments on the manuscript.

REFERENCES

Boyd, I.L., D.J. McCafferty, K. Reid, R. Taylor and T.R. Walker. 1998. Dispersal of male and female Antarctic fur seals *Arctocephalus gazella*. *Can. J. Fish. Aquat. Sci.*

Boyd, I.L., E.J. Hawker, M.A. Brandon and I.J. Staniland. In press. Measurement of ocean temperature using instruments carried by Antarctic fur seals. *Journal of Marine Systems*.

Brierley, A. S. and J.L. Watkins. 1996. Acoustic targets at South Georgia and the South Orkney Islands during a season of krill scarcity. *Mar. Ecol. Prog. Ser.*, 138 (1–3): 51–61.

Brierley, A.S., J.L. Watkins and A.W.A. Murray. 1997. Interannual variability in krill abundance at South Georgia. *Mar. Ecol. Prog. Ser.*, 150 (1–3): 87–98.

Brierley, A.S., J.L. Watkins, C. Goss, M.T. Wilkinson and I. Everson. 1999. Acoustic estimates of krill density at South Georgia, 1981 to 1998. *CCAMLR Science*, 6: 47–57.

Demer, D.A. 1994. Accuracy and precision of echo integration surveys of Antarctic krill. Ph.D. thesis, University of California, San Diego: 144 pp.

Foote, K.G., I. Everson, J.L. Watkins and D.G. Bone. 1990. Target strengths of Antarctic krill (*Euphausia superba*) at 38 and 120 kHz. *J. Acoust. Soc. Am.*, 87 (1): 16–24.

Greene, C.H., P.H. Wiebe, S. McClatchie and T.K. Stanton. 1991. Acoustic estimates of Antarctic krill. *Nature*, 349: 110 pp.

Hill, H.J. 1990. A new method for the measurement of Antarctic krill, *Euphausia superba* Dana, from predator food samples. *Polar Biol.*, 10 (4): 317–320.

Lockyer, C. 1973. Wet weight, volume and length correlation in the Antarctic krill *Euphausia superba*. *Discovery Reports*, 36: 152–155.

Morris, D.J., J.L. Watkins, C. Ricketts, F. Bucholz and J. Priddle. 1988. An assessment of the merits of length and weight measurements of Antarctic krill *Euphausia superba*. *Brit. Ant. Surv. Bull.*, 79: 37–50.

Murphy, E.J. and K. Reid. In press. Modelling Southern Ocean krill population dynamics: biological processes generating fluctuations in the South Georgia ecosystem. *Mar. Ecol. Prog. Ser.*

Reid, K. 2000. A description of the ecosystem status at South Georgia during winter 1999–summer 2000. Document *WG-EMM-00/19*. CCAMLR, Hobart, Australia.

Reid, K. and J.P.Y. Arnould. 1996. The diet of Antarctic fur seals *Arctocephalus gazella* during the breeding season at South Georgia. *Polar Biol.*, 16 (2): 105–114.

Reid, K. and J. Measures. 1998. Determining the sex of Antarctic krill *Euphausia superba* using carapace measurements. *Polar Biol.*, 19: 145–147.

Reid, K., P.N. Trathan, J.P. Croxall and H.J. Hill. 1996. Krill caught by predators and nets: differences between species and techniques. *Mar. Ecol. Prog. Ser.*, 140 (1–3): 13–20.

Reid, K., K. Barlow, J. Croxall and R. Taylor. 1999a. Predicting changes in the Antarctic krill *Euphausia superba* population at South Georgia. *Mar. Biol.*, 135: 647–652.

Reid, K., J. Watkins, J. Croxall and E. Murphy. 1999b. Krill population dynamics at South Georgia 1991–1997, based on data from predators and nets. *Mar. Ecol. Prog. Ser.*, 117: 103–114.

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